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EFFECTIVENESS OF A SONIC DEVICE IN REPELLING ADULT ALEWIFE AT THE PICKERING NUCLEAR GENERATING STATION

Report No 87-117-K

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ABSTRACT

The objective of this study was to determine the effectiveness of a sonic device in repelling adult alewife in the vicinity of the Pickering Fish Diversion System. Results indicated that the sonic capabilities of the hammer were effective in significantly reducing the number of inshore and offshore moving alewife. No evidence of habituation was apparent since continuous operation of the hammers for six hours consistently reduced the number of alewife caught at the Diversion System. Results also suggested that several hammers elicited a far field negative response from adult alewife at a distance of at least 5-10 metres. Sonic deterrents are recommended as a method for repelling onshore moving adult alewife at the Pickering Nuclear Generating Station.

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EXECUTIVE SUMMARY

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The objective of this study was to determine the effectiveness of a sonic device in repelling adult alewife in the vicinity of the Pickering Fish Diversion System. The deterrent evaluated, referred to as a hammer, is a spring-mass impact device which produces a repetitive sharp sound of relatively high amplitude sound pressures by exciting resonant vibration modes of a structure which is in direct coupling with surrrounding water. The duration of the signal was approximately 200 ms. The output of the hammer used during this study resembled a previously evaluated and successful deterrent, the pneumatic popper, in terms of frequency (52.5 Hz). The hammer however, produced a significantly greater sound amplitude (5 times). Two types of experiments were conducted, one using a single hammer per structure and one using two hammers per structure. Results indicated that two hammers per structure effectively reduced the number of inshore moving alewife caught (85%). The number of inshore moving alewife in the general vicinity of the Diversion System was also significantly reduced. No evidence of habituation was apparent since continuous operation of the hammers for six hours consistently reduced the number of alewife caught at the Diversion System.

A wide range of behavioural barriers have been evaluated at the Pickering Diversion System over the past three years. Devices examined have included strobe lights, rope net, air bubbles and pneumatic poppers. Of all individual deterrents evaluated, the popper had the largest area of influence, approximately 5 metres. There were however, concerns regarding the mechanical reliability of this device. This was one of the reasons why the hammer was

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developed. Results of this study indicated that the hammers had an area of influence of between 5 and 10 metres.

Hammers are recommended as sonic deterrents to onshore moving alewife at the Pickering Nuclear Generating Station.

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EFFECTIVENESS OF A SONIC DEVICE IN REPELLING ADULT ALEWIFE AT THE PICKERING NUCLEAR GENERATING STATION

INTRODUCTION

Fish loss resulting from impingement at generating stations using the once-through-cooling process has been the subject of much research. Minimization of these losses can potentially be achieved by the use of protection schemes which have involved mechanical or behavioural means of handling fish. While both means have proven effective in some instances, behavioural methods have the advantage of being relatively inexpensive and not influencing station operation. Furthermore, behavioural schemes rely on the innate response of fish to various stimuli and do not require the physical handling of this resource.

The use of sound as a behavioural stimulus for controlling fish movement has recently received considerable attention (Haymes and Patrick 1984, Haymes and Patrick 1985, Schwarz 1985 and McKinley and Patrick 1986, 1987). A single pneumatic popper, which produced high amplitude, low frequency sound has proven effective for excluding adult alewife (Alosa pseudoharengus) at the Pickering Diversion System (Haymes and Patrick 1985/86). There were however, reliability problems with the popper which would limit its potential use at generating stations. Furthermore, the fixed operating frequency and amplitude level of the popper has been shown not to be effective for other species such as coho salmon (Patrick 1985) and white perch (preliminary laboratory results). Other studies have also indicated that there is a species-specific response to sound (Ray et al. 1976, Hocutt 1980) and therefore a need for an effective sound device capable of generating various frequency and amplitude levels exists.

Recently, a device, referred to as the "fish pulser" (hammer), capable of mimicking the acoustical output of a popper has been developed. Furthermore, this device can be tuned to specific sound frequency in response to the sensitivity of the targeted

species with minimal modification. Preliminary evaluation of the hammer at Pickering indicated a percent effectiveness of 61% for inshore moving alewife, which was slightly less than that of the popper (71%), although not statistically different (McKinley and Patrick 1987). During these experiments, the prototype was however, inadequate since its housing leaked which limited its acoustical capability. Further refinements of the mechanical reliability were conducted in the early winter of 1986. The objective of this study was to evaluate the effectiveness of an improved design of the hammer in repelling adult alewife at the Pickering Fish Diversion System.

MATERIALS AND METHOD

Hammer

The hammer is a spring-mass impact device which produces a repetitive sharp sound of relatively high amplitude sound pressures by exciting resonant vibration modes of a structure which is in direct coupling with the surrounding water (McKinley and Patrick 1986). The duration of signal (time to decay by a factor of 10) is approximately 200 ms. The output of the hammer used during this study (6 mm end plate) resembled that of the pneumatic popper with respect to fundamental frequency (52 Hz) and time history (Figure 1). There were however, slight differences in the frequency spectrum produced by the devices (McKinley and Patrick 1986). The hammer, due to the resonance of the enclosure, produced sound which was generally more broad band than the popper (McKinley and Patrick 1986). These higher frequencies (>550 Hz) probably played less of a role than the lower frequencies in eliciting a response in alewife and are due to the resonance from the hammer's enclosure. Sound pressure levels produced by the hammer were however, at least five times greater than that of the popper.

Study Site

This investigation was conducted at the Pickering diversion system situated approximately 25 km east of Toronto on Lake Ontario. The diversion system is situated 78 m offshore from the surface intake of Pickering NGS (Figures 2 and 3). The system included two 9 m wide identical structures. Each of the structures consisted of nine 0.3 m pilings arranged in three rows and have been described in previous reports (Haymes and Patrick 1984, 1986). The north pilings (2) of both structures supported frame nets which consisted of three, 3.8 cm stretched mesh gill nets supported in a metal frame. Together these nets fished the entire water column (6 m) behind each structure. Hammers were

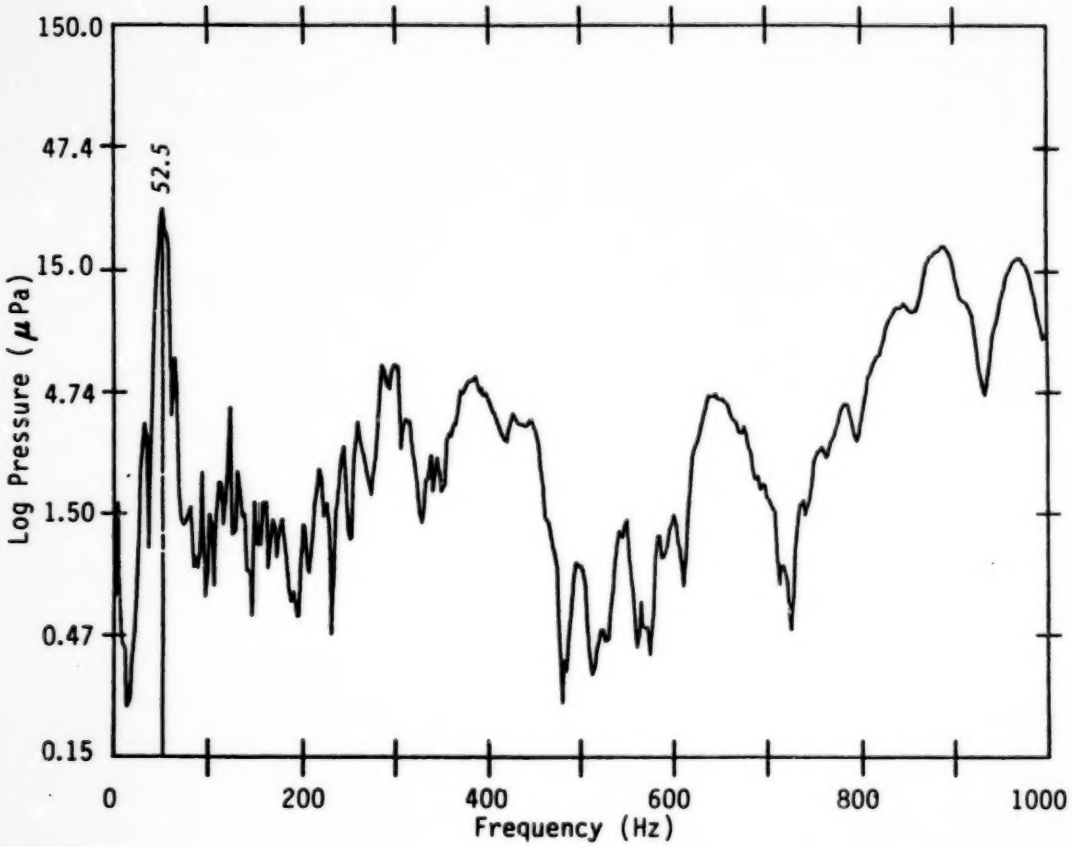


FIGURE 1

FREQUENCY SPECTRUM OF THE ACOUSTICAL PRESSURE MEASURED FROM A SINGLE HAMMER (6mm END PLATE) (PICKERING FISH DIVERSION SYSTEM, 1986)

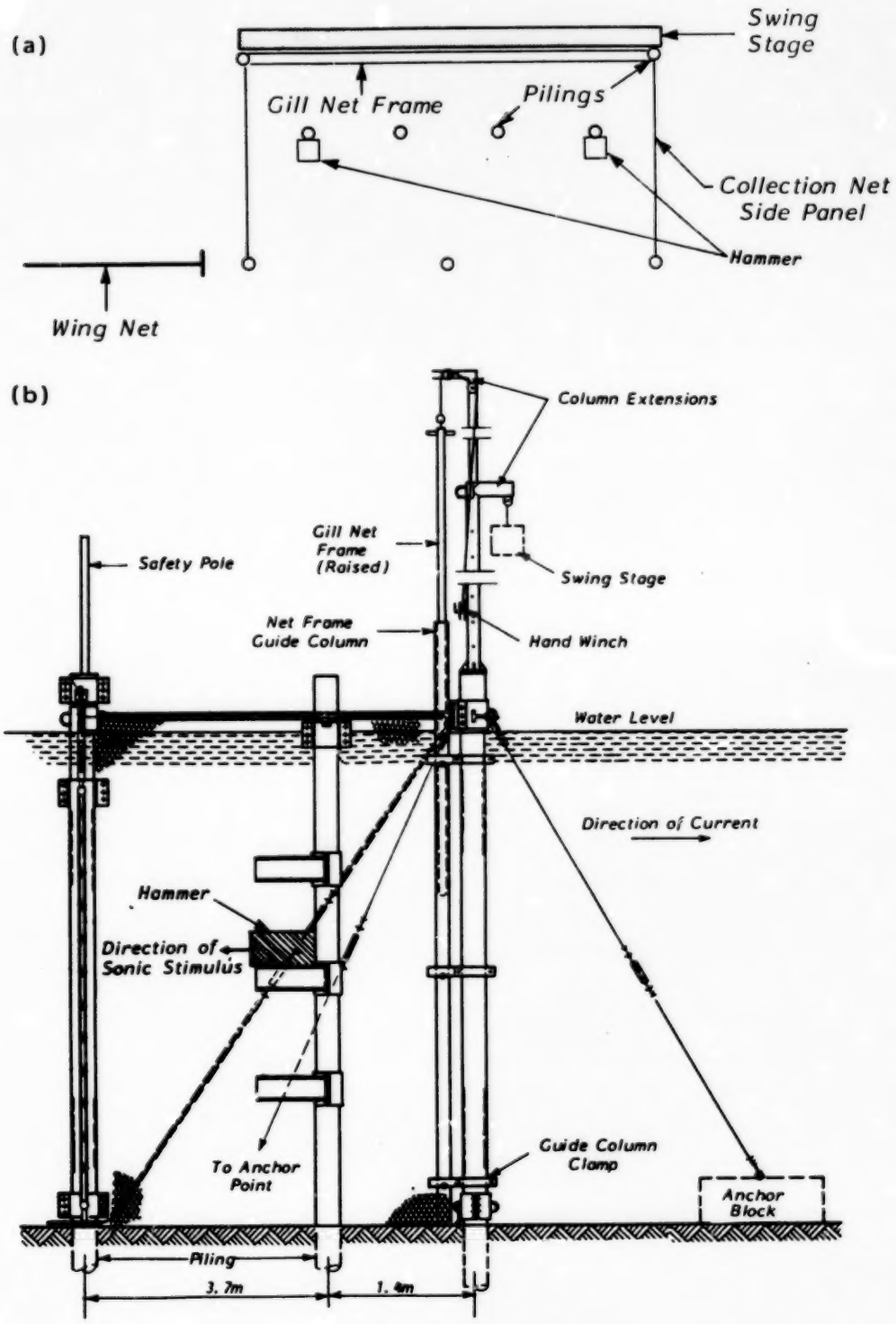


FIGURE 2

TOP (a) AND SIDE (b) VIEWS OF EXPERIMENTAL STRUCTURE FISH DIVERSION TEST SYSTEM

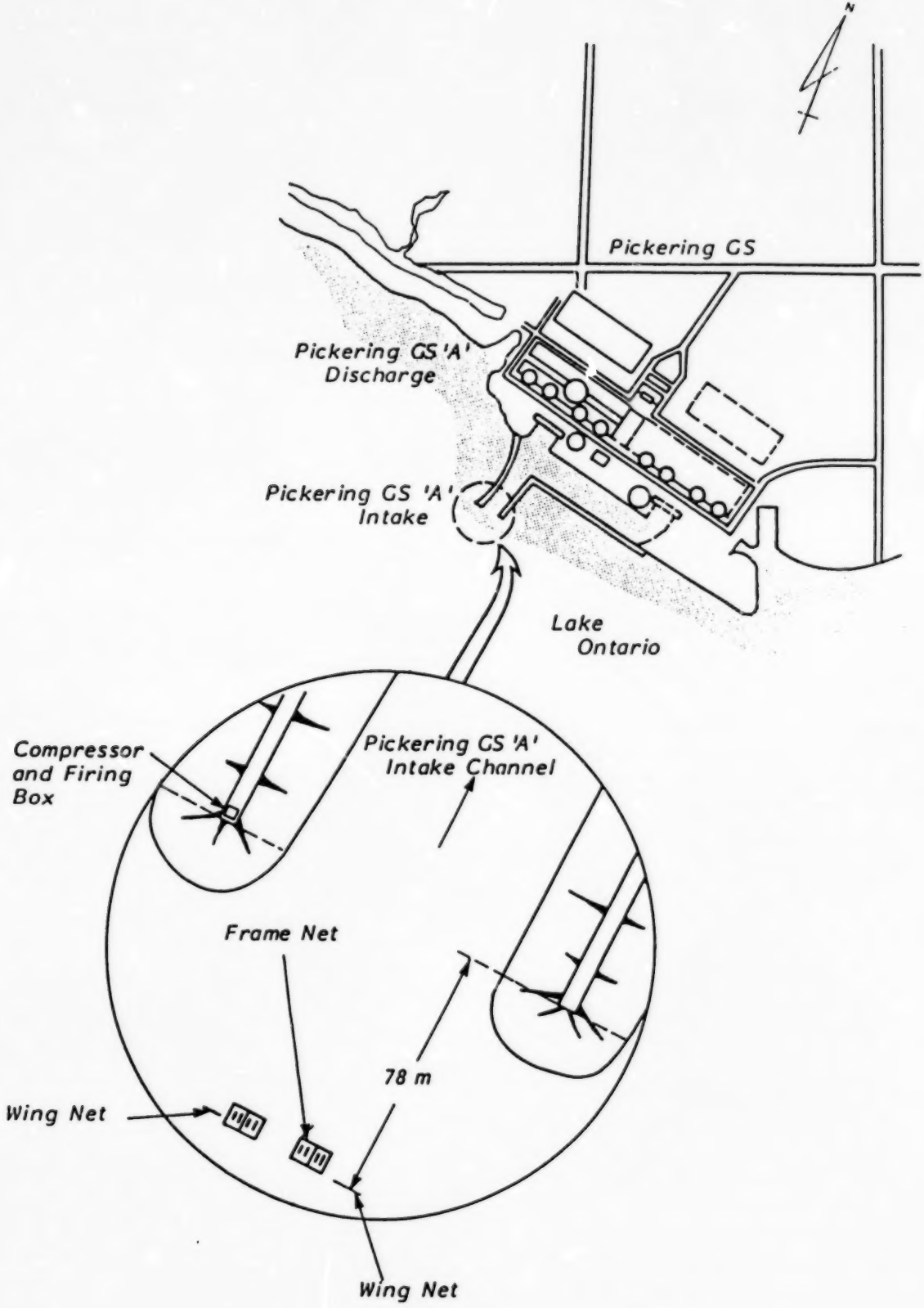


FIGURE 3

FISH DIVERSION TEST SYSTEM
PICKERING GENERATING STATION

positioned at the three metre depth on either end of the middle set of pilings (Figure 2).

Experimental Procedure

A pneumatic popper was evaluated using a paired statistical design (Haymes and Patrick 1986 and McKinley and Patrick 1986b). This involved comparing the number of fish caught in the west structure (experimental) compared to those caught in a concurrent control (east structure). Preliminary analyses of fish catches and acoustical pressure levels in the vicinity of the Diversion System indicated that a single hammer could influence the neighbouring structure. This was not unexpected since using more than one popper, which had acoustical energy still less than that of a single hammer, was also found to influence the neighbouring structure (Haymes and Patrick 1986). Experimental design was therefore systematically stratified. Two types of experiments were conducted, one using a single hammer and those using two hammers per structure. Since the hammer sound pulses appeared directional, it was felt that two hammers would provide a more complete coverage of the Diversion System.

The effectiveness of the hammer was determined by comparing the number of adult alewife caught at both structures with no hammers operating (control) to those caught during the operation of one or two hammers per structure (experimental). Control tests (n=17), as part of another project, were conducted just prior to the hammer evaluation. These tests determined whether alewife catch varied between the east and west structures with no hammers operating. These data were used to assess whether the east or west structure was biased with respect to the number of fish caught. Duration of each experiment was 2 h which previous studies have indicated was a sufficient time period for a representative sample size (Haymes and Patrick 1986). Experiments were conducted between 2200 and 0200 h when fish movement was greatest (Haymes and Patrick 1986 and McKinley and Patrick 1986b). Hammmer and control tests were conducted between June 23 and July 17. Previously conducted paired control data were collected between May 6 and June 23.

The long term effectiveness of the hammer was determined by comparing the number of alewife caught during control conditions to those caught at three consecutive, experimental two hour intervals. These data were collected for any evidence of habituation by alewife to the hammer over a six hour period.

In addition to the collection nets (frame nets) on the structures, bottom set gill nets (15.2 m., 3.2 cm mesh,1.7 m height) were placed to the east and west of the diversion system. These nets (wing nets) gave an indication of alewife movement in the

vicinity of the two structures. Wing net catches from both the east and west structures were also compared under control conditions (no hammers operating) for any evidence of bias directed towards the general vicinity of either structure. At the end of each test the wing and frame nets were lifted in the same sequence in which they were set. The direction (ie. inshore or offshore) and location (frame nets - top 0-2, middle 2-4, bottom 4-6 m) of fish caught were noted.

An acoustical fish census system was also used to supplement the catch data and determine fish distribution in front of both structures. These data were also intended to measure the extent of fish response to the hammer(s). The system consisted of a modified transmitter and transducer (Edo Western), time-varied gain receiver (Ithaco) and a fibre-optic graphic recorder (Honey-Well). The fish counting system was designed with sufficient sensitivity and resolution for location and separation of fish 15 cm apart at a distance of 100 m. Echoes were automatically counted and separated into six selectable depth ranges and four selectable amplitude (size) ranges. Digital output of echoes was printed at 30 second intervals. Tracings of echoes were also recorded as a separate output. A transducer was directed at each structure from a distance of 33 metres.

Acoustical data were determined at distance intervals of 0 - 5, 5 - 10, 10 - 15, 15 - 20, 20 - 25 and 25 to 33 m from both west and east structures. Data acquisition was alternated between each structure every 15 minutes over the two hour test period. Due to interference from the operation of the hammer with the acoustical system, quanitative data (digital output) using sonar could not be obtained. School size and distribution therefore, were only visually reviewed from the visicorder output during control and experimental conditions.

For each test, turbidity and temperature in front of each structure at the surface, mid-depth and bottom were determined using a Sargent-Welch turbidimeter and Hydrolab (4041) meter, respectively. Sound pressure measurements (kPa) were recorded at two metre intervals along a horizontal plane to a maximum distance of 10 metres from each structure. Measurements were recorded along transects positioned in front, behind and to each side of the structures. These measurements were conducted at depths of 1.5 and 3 metres. The measuring system consisted of a Celesco LC 32 hydrophone connected to a pre-amplifier (sound and vibration analyzer type 1564-4). Data were recorded on a Hewlett-Packard tape recorder, analyzed with a Data Precision wave form analyzer (Data 6000) and plotted with a Hewlett-Packard (Model 7470) digital plotter.

Data Analysis

A three-way ANOVA was used to compare the experimental treatment (one or two hammers per structure) to the control (no hammers operating) over the depth distribution on the frame net on different dates. Interactions between treatment and depth, date and treatment and date and depth were also examined. The F-statistic for all catch data are given in Appendix A. Prior to analysis, all data were log transformed to satisfy assumptions inherent in the use of ANOVA. The measure of confidence adopted for all these tests was the 5% level of significance.

Percent reduction (E) of a particular deterrent was defined as the difference in the number of alewife caught between experimental and control test periods:

$$E = [C(\text{control}) - C(\text{experimental})] / C(\text{control}) \times 100\%$$

where C(control) and C(experimental) are the number of inshore or offshore moving alewife in both structures during either test period.

RESULTS

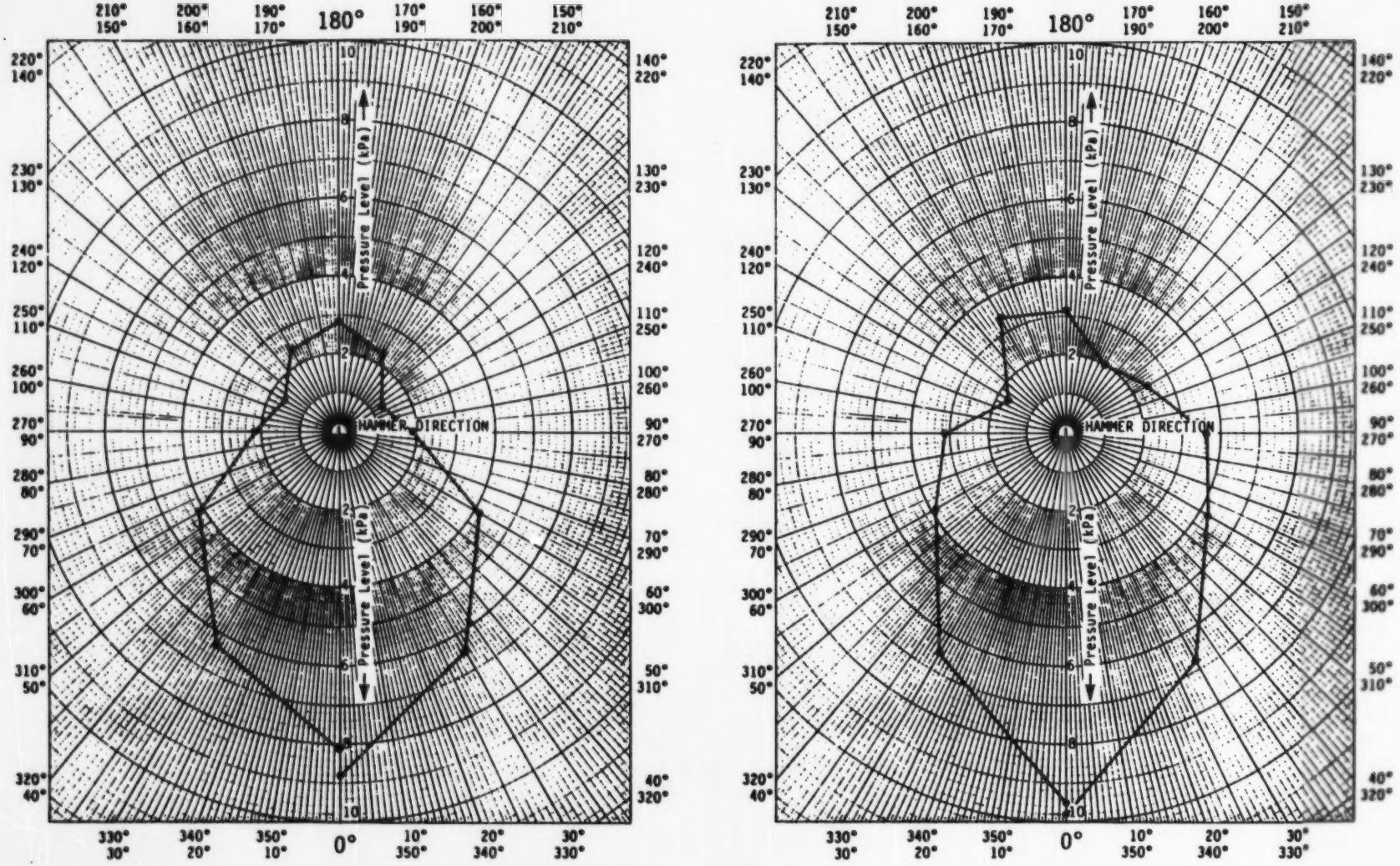
Temperature and Turbidity Measurements

Water temperature over the course of study varied considerably, ranging from a low of 2°C to a high of 18°C. Temperatures were generally slightly higher on the surface and lowest at the bottom. Average temperature between the east and west structures were similar (Table 1).

Similarly, turbidity levels were also similar between the east and west structures (Table 1). There was little difference in turbidity levels throughout the water column.

Sound Pressure Measurements

Sound pressure (kPa) measurements were taken directly in front, behind and to each side of the hammer. Sound emitted from the hammer was extremely directional (Figures 4a and b). The pressure levels, recorded at a distances of 10 m from the hammer, were approximately 8 to 10 kPa directly in front compared to approximately 2 kPa behind and to either side of the hammer.



(a)

Hydrophone positioned at 1.5 m depth

(b)

Hydrophone positioned at 3.0 m depth

FIGURE 4

SOUND PRESSURE LEVELS (kPa) EMITTED ABOUT A HAMMER AT DISTANCES OF 10m

Table 1

Mean, Standard deviation and Range of Physical parameters measured at the Pickering Fish Diversion Structure - 1986

	East structure				West structure			
	n	Mean	SD	Range	n	Mean	SD	Range
Temperature (degrees C)	3	8.2	0.5	(5 - 18)	3	7.9	0.5	(2 - 18)
Turbidity (NTU)	3	1.3	0.3	(.9 - 2.9)	3	1.6	0.4	(1 - 2.9)

Spatial Distribution of Alewife

Paired Control Data

The number of inshore moving alewife was generally equally distributed between the two structures (Figure 5). The number of alewife caught in the east structure was not significantly different from the number caught in the west structure (Table 2). For offshore moving fish, catches in the east structure were slightly higher (12%), but not significantly different, than that observed at the west structure. These data indicated that little or no difference in alewife distribution between structures prior to the hammer/control tests.

Similarly, wing net data showed that alewife distribution and abundance were similar in the vicinity of both structures (Figure 6). No significant difference between the two structures existed, for both offshore and inshore moving alewife, when no deterrent was operating (Table 2).

Hammer Effectiveness

Frame/Wing Net Results

Single Hammer

Overall, one hammer per structure was only effective in significantly reducing ($F=9.27$, 1, 6, $p<0.05$) the frame net catch of offshore moving adult alewife (Table 3). The majority of these fish were caught in the top portion (4 - 6 m) of the frame net during both control and experimental tests (Figure 7). Here sound pressures levels from a hammer positioned at the 3.0 m depth would have been greatly reduced. This is reflected in a insignificant reduction (15%) in fish at this depth. At the remaining middle and bottom depths, the percent effectiveness was 65 and 82%, respectively.

Wing net catches indicated that one hammer per structure was ineffective in reducing the number of adult alewife caught in the immediate vicinity of the Diversion System. The mean catch of inshore and offshore moving alewife was highly variable during experimental and control tests and any dissimilarity was not apparent (Table 3).

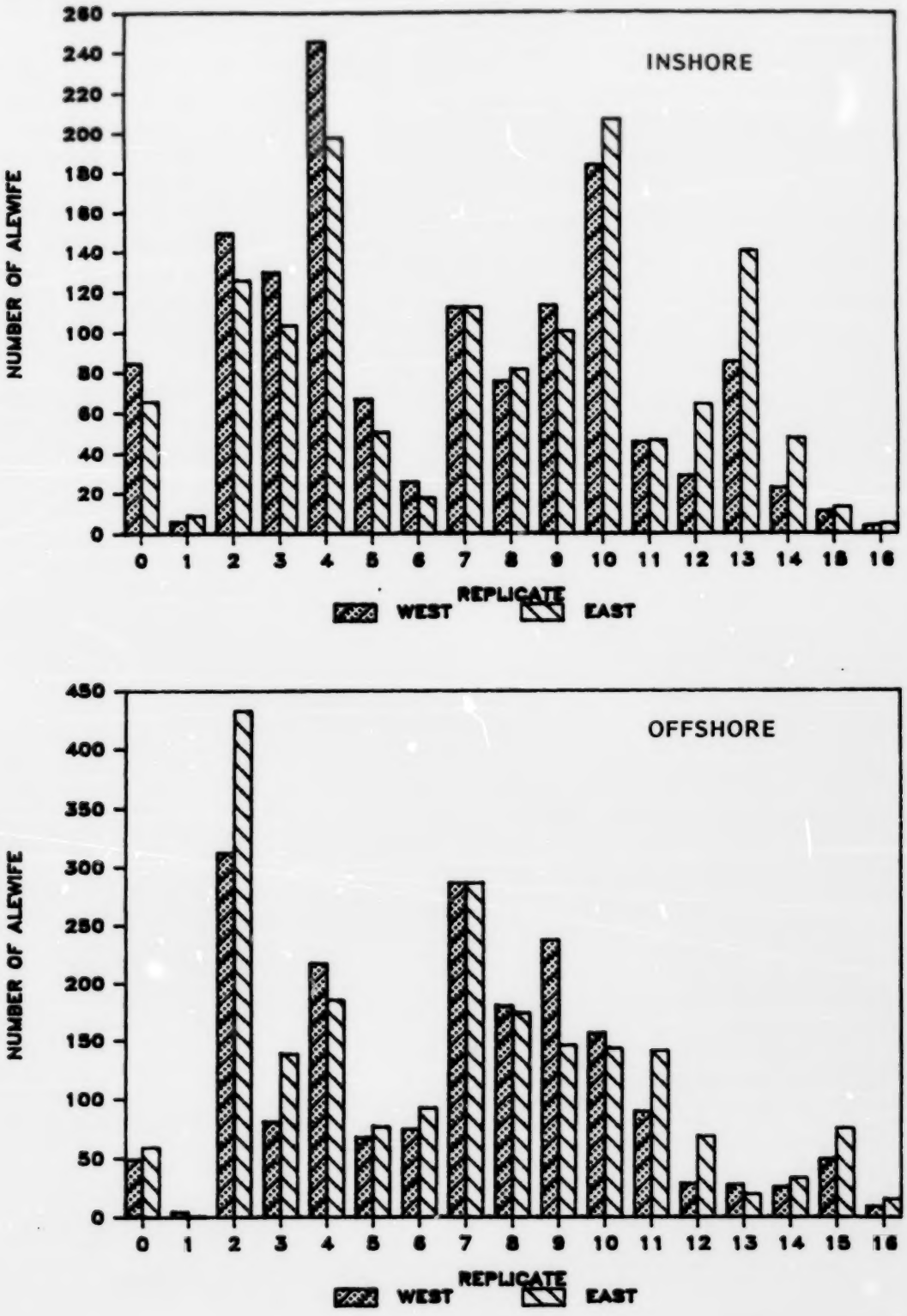
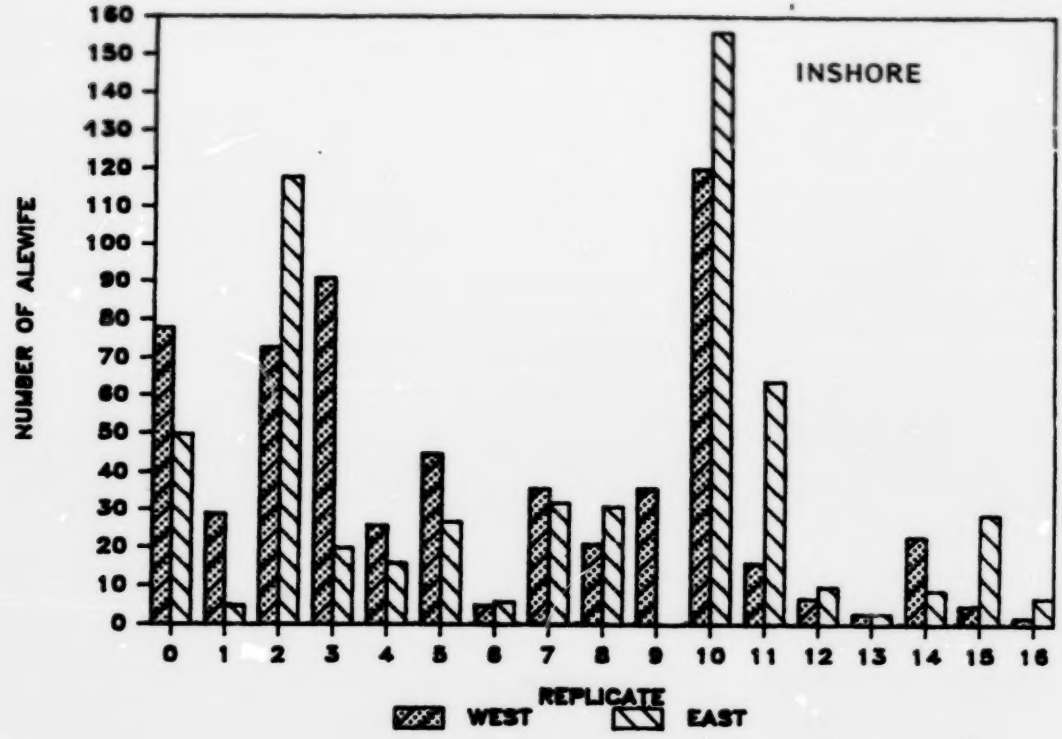


FIGURE 5
NUMBER OF ALEWIFE CAUGHT IN WEST AND EAST
FRAME NETS DURING CONTROL TESTS
1986
(From EPRI, McKinley and Patrick, 1987)



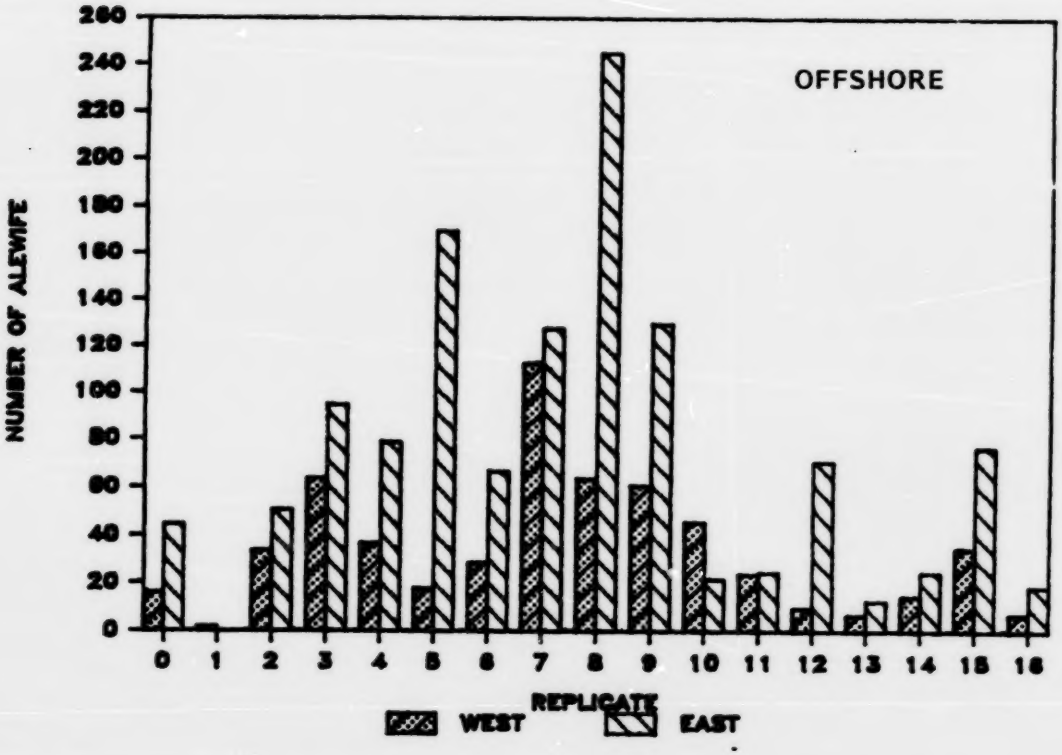


FIGURE 6

NUMBER OF ALEWIFE CAUGHT IN WEST AND EAST WING NETS DURING CONTROL TESTS 1986

From EPRI, McKinley and Patrick, 1987.

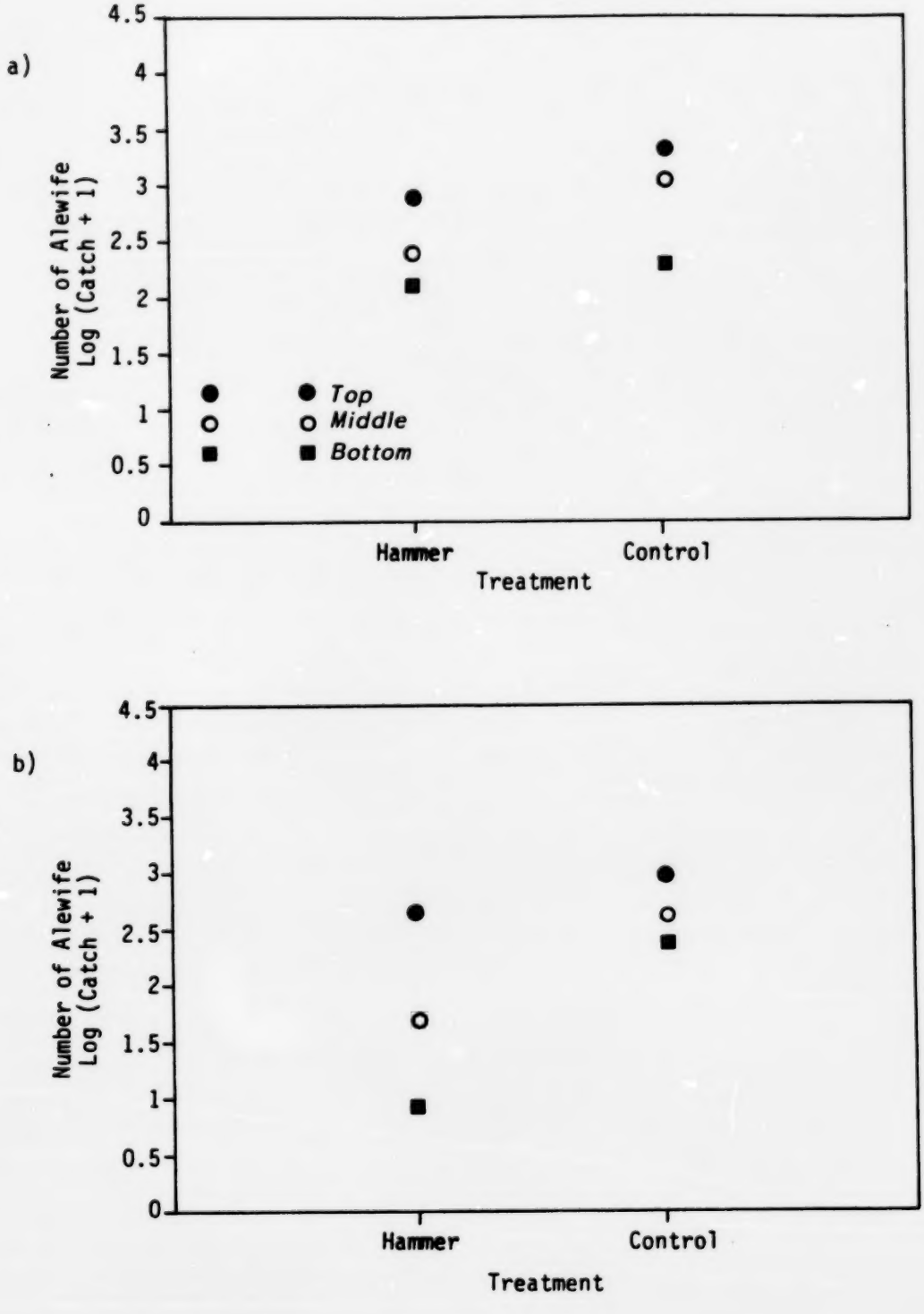


FIGURE 7

DISTRIBUTION OF ALEWIFE CAUGHT IN FRAME NETS DURING CONTROL AND EXPERIMENTAL (ONE HAMMER PER STRUCTURE) TESTS

a) INSHORE MOVING FISH
b) OFFSHORE MOVING FISH

Table 2

Number of alewife collected in frame and wing nets with no deterrent operating

Alewife Direction	Frame nets					
	West			East		
	n	Mean	SD	n	Mean	SD
Inshore	17	82.7	17.1	17	82.0	61.4
Offshore	17	110.1	96.8	17	123.5	108.5
	Wing nets					
	West			East		
	n	Mean	SD	n	Mean	SD
Inshore	17	36.2	34.7	17	36.4	43.3
Offshore	17	34.2	28.6	17	74.2	28.6

(From EPRI, McKinley and Patrick, 1987)

Table 3

Number of Alewife Collected in Frame and Wing nets during Control and Experimental Tests

	Experimental						Control						Percent Effectiveness *	
	inshore			offshore			inshore			offshore			inshore	offshore
ONE HAMMER	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD		
Frame Nets	4	41.3	21.9	4	27.3	22.7	4	74.8	55.3	4	49.8	27.0	45	46
Wing Nets	4	51.0	36.0	4	26.0	14.2	4	59.0	26.7	4	34.0	27.0	14	24
TWO HAMMERS														
Frame Nets	10	41.0	27.0	10	39.0	28.0	10	263.0	167.8	10	138.3	71.4	85	72
Wing Nets	10	83.0	46.0	10	69.2	45.7	10	143.0	76.0	10	106.0	59.6	42	35

* Percent Effectiveness = (E - C) / C X 100, where E = Experimental catch and C = Control catch.

Multiple Hammers

The percent effectiveness of the two hammers per structure in reducing the total frame net catch of inshore and offshore moving adult alewife was 85 and 72, respectively. These significant reductions in inshore and offshore moving alewife ($F=524.9$, d.f.= 1, 18 and $F=266.9$, d.f.= 1, 18, respectively) were consistent throughout the entire test period (Figure 8a and b). Furthermore, inshore directed fish were similarly reduced throughout the water column (Figure 9a). Behind the structures, all fish were also similarly reduced, regardless of depth, during the two hammer tests (Figure 9b).

In addition, the operation of two hammers per structure effectively reduced wing net catches of inshore and offshore moving alewife (Figure 10a and b). These significant reductions in offshore and inshore moving alewife ($F=13.0$, d.f.=1,9 and $F=27.9$, d.f.=1,9, respectively) occurred for at least 80% of the tests. These reductions averaged 42% for inshore moving fish (Table 3).

Long term operation of two hammers for six hours resulted in a consistent and significant reduction in the number of inshore oriented alewife (Figure 11a). A similar trend was also observed for offshore directed alewife (Figure 11b). Both trends appeared dissimilar to the temporal distribution of alewife with no behavioural devices operating just prior to the hammer evaluation (McKinley and Patrick 1986b).

The long term influence of two hammers (6 h) on wing net catches for both inshore and offshore oriented alewife was not obvious but alewife numbers did not appear to increase with time.

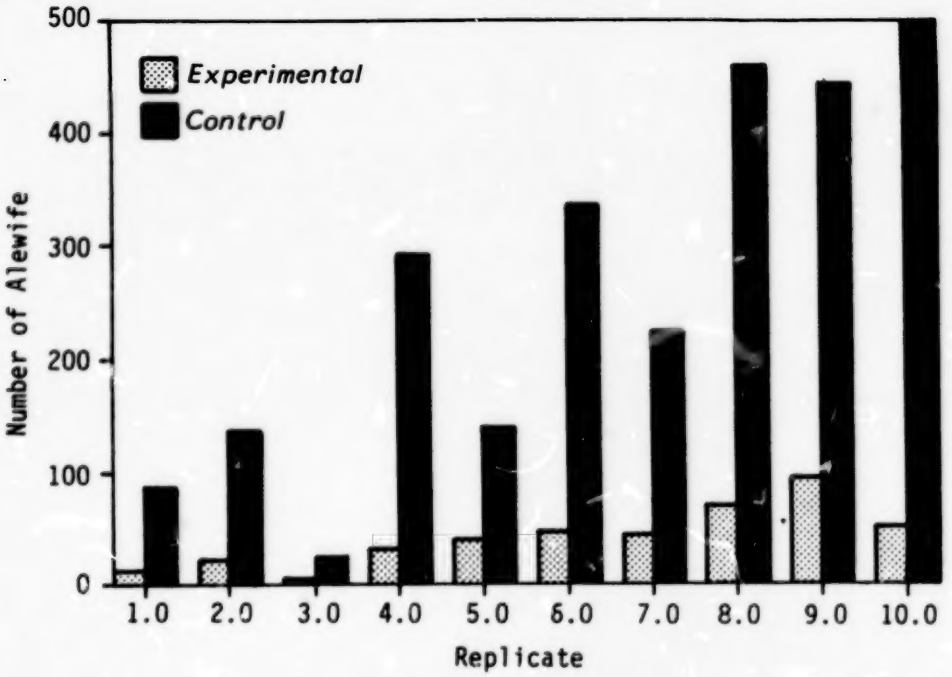
Acoustical Data

The operation of two hammers appeared to influence the distribution of potential fish echoes (Figure 12). The area of influence appeared to extend to an area at least 10 m from in front of the hammer.

DISCUSSION

A brief review of the literature indicated that use of acoustical stimuli as either a fish attractant or repellent has generally been ineffective (Moore and Neumann 1956, Brett and Alderdice 1958, Ray *et al.* 1976, Hocutt 1980 and Smith and Anderson 1984). Lack of success was attributed to a species-specific response to sound and/or the inability of the device to produce appropriate frequencies or energy levels for the desired behavioural response. The recent success of an early study in eliciting a negative response in adult alewife using a pneumatic popper and

a)



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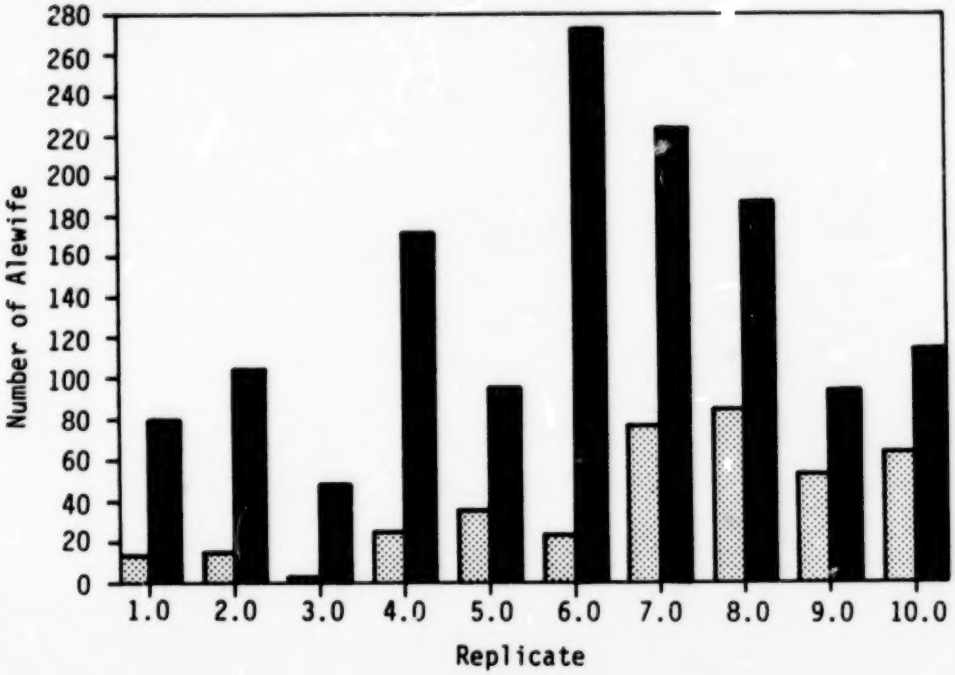
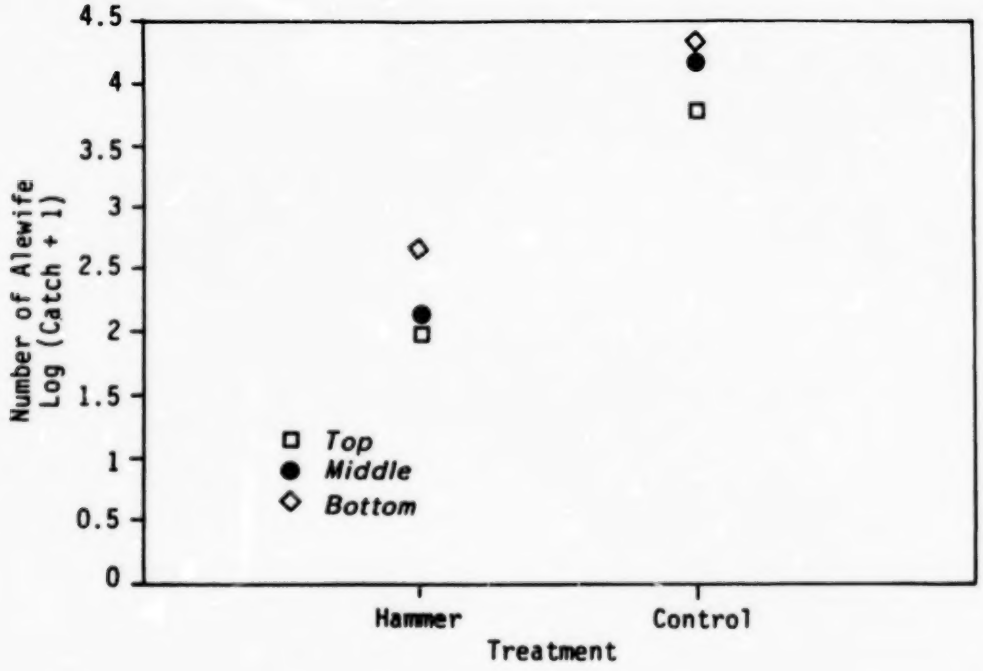


FIGURE 8

NUMBER OF ALEWIFE CAUGHT IN FRAME NETS DURING CONTROL AND EXPERIMENTAL (TWO HAMMERS PER STRUCTURE) TESTS

a) INSHORE MOVING FISH
b) OFFSHORE MOVING FISH



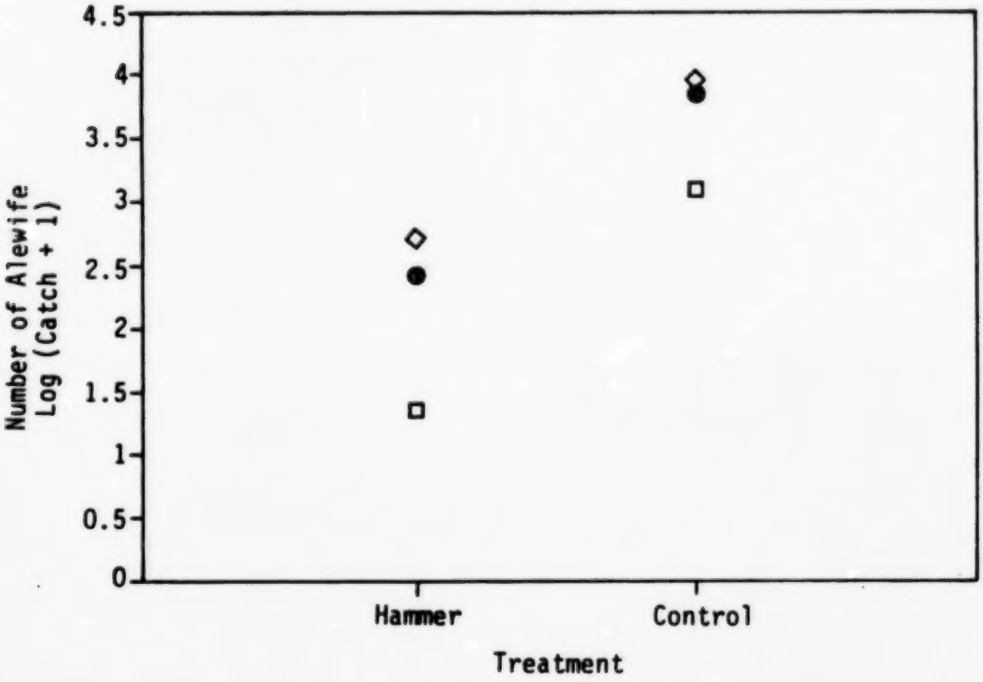
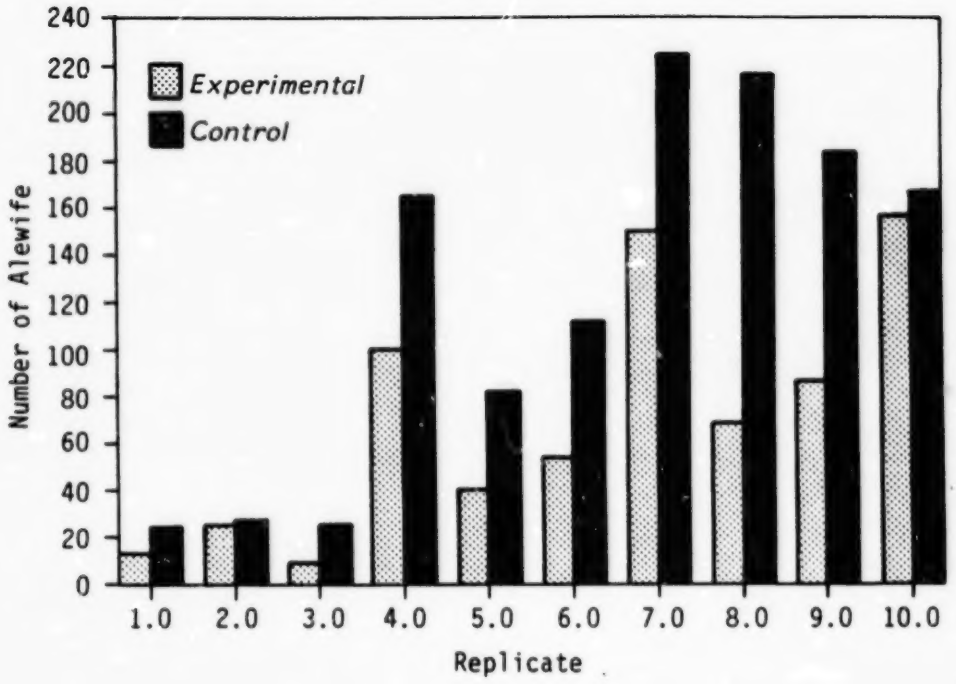


FIGURE 9

DISTRIBUTION OF ALEWIFE CAUGHT IN FRAME NETS DURING CONTROL AND EXPERIMENTAL (TWO HAMMERS PER STRUCTURE) TESTS

a) INSHORE MOVING FISH
b) OFFSHORE MOVING FISH

a)



b)

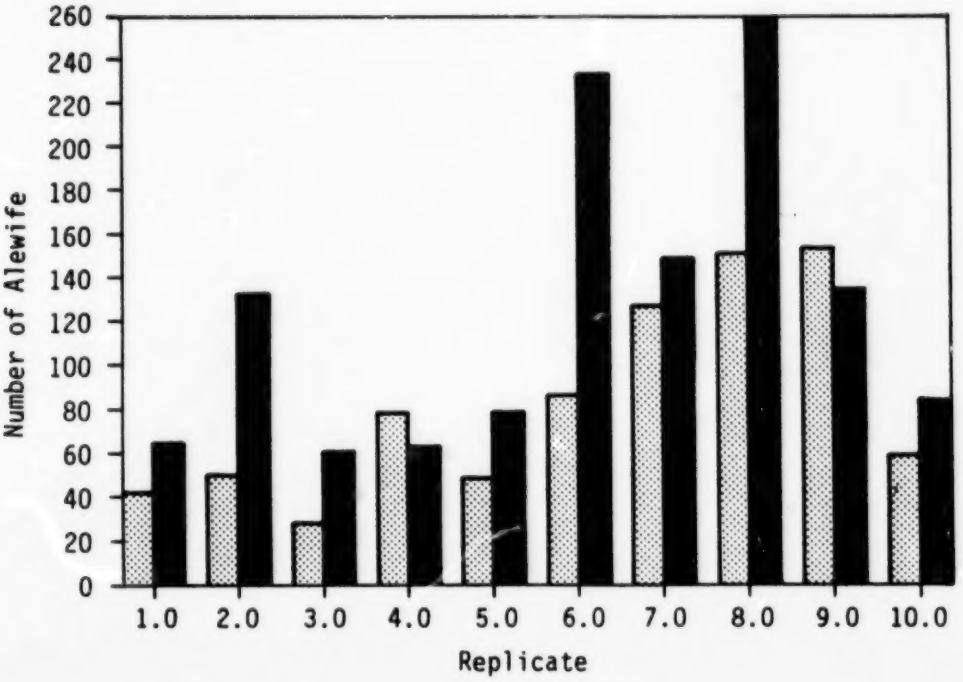


FIGURE 10
NUMBER OF ALEWIFE CAUGHT IN WING NETS DURING CONTROL AND EXPERIMENTAL (TWO HAMMERS PER STRUCTURE) TESTS
a) INSHORE MOVING FISH
b) OFFSHORE MOVING FISH

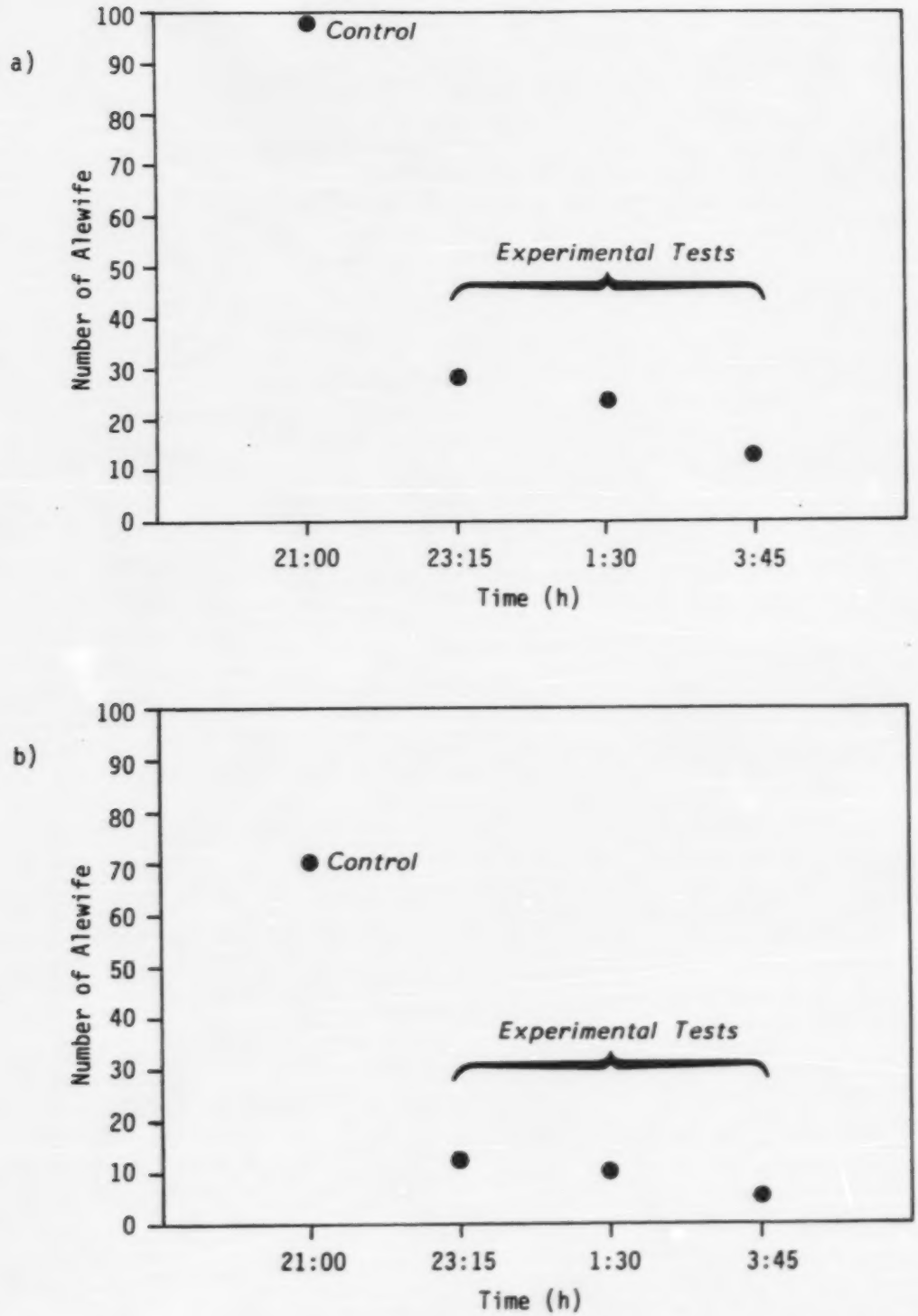


FIGURE 11 .

NUMBER OF ALEWIFE CAUGHT IN FRAME NETS DURING ONE CONTROL AND THREE CONSECUTIVE EXPERIMENTAL (TWO HAMMERS PER STRUCTURE) TESTS

a) INSHORE MOVING FISH
b) OFFSHORE MOVING FISH

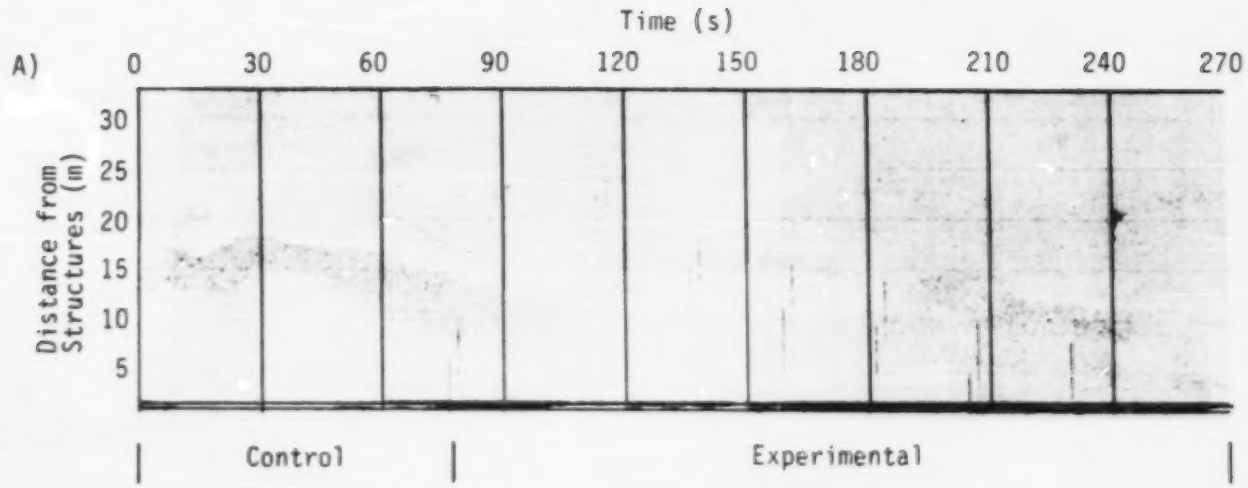


FIGURE 12

DISTRIBUTION OF ECHOES DURING CONTROL AND EXPERIMENTAL CONDITIONS AT THE PICKERING FISH DIVERSION SYSTEM. NOTE REGULAR PATTERN OF DOTS AND SPIKES DURING OPERATION OF THE HAMMER(S)

an early version of the hammer suggested the need for the production of a significant sound amplitude (Haymes and Patrick 1986 and McKinley and Patrick 1986). Results of this study indicated that the increased negative response of adult alewife, 85% compared to 73 and 61% for the popper and the early hammer respectively, was probably due to the much improved energy output of the hammer. This requirement of a significant amplitude or shock wave to elicit a marked avoidance response from fish was first speculated by Schuler and Larson (1975). The effect of the hammer's improved signal output in repelling inshore moving alewife during this study supports their hypothesis.

Results also indicate that a single hammer is not capable of significantly reducing the number of adult alewife in the frame nets. This limitation appeared to be directly related to the directionality of the acoustic signal from the hammer as evident from its selective influence on the three sections of the frame net as well as problems in alignment (Figure 7). The signal output of two hammers however, reduced the number of alewife caught throughout the entire frame net.

Continuous exposure of adult alewife to the hammer did not result in habituation, in terms of frame net catch, to the acoustical signal. The operation of four hammers continued to maintain significantly reduced alewife numbers in the vicinity of the Pickering Diversion System for six hours. Numbers of individuals susceptible for collection in the nets were assumed to be relatively constant during the six hour tests based on previous temporal data (Haymes and Patrick 1986 and McKinley and Patrick 1986). While this asssumption is admittedly weak, preliminary laboratory and field data have suggested that other species such as gizzard shad and white perch do not habituate after long term exposure (2 h) to the hammer.

A wide range of behavioural barriers have been evaluated at the Pickering Diversion System over the past several years. Devices examined have included strobe lights, rope net, air bubbles and a pneumatic popper. Of all the individual deterrents evaluated, the popper reduced the number of adult alewife caught in the frame net to the greatest extent. Its area of influence was found to be approximately five metres (McKinley and Patrick 1987). Results of this study indicated that the hammer elicited a far field negative response from alewife at a distance of between 5 and 10 metres.

Overall, results demonstrated the importance of sound, particularly sound amplitude, in eliciting a negative response in adult alewife. The importance of sound amplitude or pressure has previously been suggested as playing the predominant role in

initiating startle responses among clupeids (Blaxter et al., 1981). Furthermore, a rapid rise of the high amplitude signal has been shown to be a very important trait for producing a startle response in both Atlantic and Pacific herrring (Schwarz and Greer, 1984 and Blaxter et al., 1981, respectively). This trait is also a characteristic of the hammer.

CONCLUSIONS

1) Operation of two hammers per structure effectively reduced the number of inshore moving alewife caught (85%). Catches of inshore moving alewife were also significantly reduced in the general vicinity of the Diversion System.

2) Operation of two hammers for six hours resulted in a consistent and significant reduction in the number of inshore oriented alewife caught in the frame nets.

3) Based on sonar tracings, the area of influence of two hammers per structure was approximately 10 metres.

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